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Fundamentals of «Smart» Greening of Technogenic Space in Industrial Cities

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Abstract: The transition to a digital economy initiates the improvement of the management of complex production systems using information technologies, including in solving interdisciplinary socially significant environmental problems. The mandatory conditions for the construction of "smart" landscaping facilities in industrial man-made areas are discussed, which should become the basis for making professional decisions. Seven fundamental principles are positioned: priority of the sanitary function; zoning of the buffer territory; the relationship between «source + marker substance + zone of active pollution» and the dispersion mechanism; scientific selection of biological plant species based on marker substances; optimization of spatial planning and design of the facility; optimal mode of operation of the facility; neural network technologies. The integration of digital technologies into air protection activities can make the achievement of «clean air» in industrial cities, as a vital value, quite real.

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1 INTRODUCTION

The idea of a «smart» industrial city is the use of neural network technologies to obtain and use information about the living environment in order to improve interaction with it, create the safest and most comfortable space (Akimova, Volkov, Khryseva, 2020). Such a city is impossible without «smart» landscaping of the most problematic industrial and transport zones, which is especially relevant for areas with a large number of residents and a high concentration of diverse industries. The current format of sanitary protection zones and buffer territories poorly provides the required protective functions due to the unprofessional selection of biological species, high wear and tear of perennial green spaces, ineffective spatial planning, and failure to comply with the required operating regime. The issues of innovative greening of public and residential spaces of cities are actively discussed by researchers, but aspects of man-made territories remain without due attention. Environmental protection greenery objects separating industrial units and residential areas serve as green filters in the best available technologies. They perform their sanitary function if they are formed and operated on the basis of well-founded decisions that take into account scientific laws, principles and requirements. The author’s goal is to outline the objective fundamentals of building «smart» landscaping in man-made areas.

2 MATERIALS AND METHODS

The methodological basis is the traditional analytical methods of scientific analysis, methods of economic and statistics, technical, economic and logical analysis, systematization and ranking. To write the article, we used normative legal acts - environmental laws and laws in the field of atmospheric air protection/

Research hypothesis: design, creation and operation of «smart» greening objects for technogenic space is a complex resource-intensive interdisciplinary environmental protection task. The contradictory nature of the complex of technical, biological, ecological, economic, social, information aspects predetermines the choice of basic priorities, the consideration and scientific analytical support of which leads to a successful solution.

To achieve this *hypothesis*, general scientific methods wereused: analysis of the thematic literature of Russian and international scientific libraries.

3 RESULTS AND DISCUSSION OF THE STUDY

The implementation of the national project «Ecology» places the protection of atmospheric air in industrial cities in the category of priority tasks. Along with the best available technologies of industry production, the construction of environmental protection landscaping facilities in buffer areas remains relevant. The development of the «smart» landscaping methodology is due to the imperfection and low efficiency of the implemented projects of sanitary protection zones of industrial enterprises and unified sanitary zones of industrial hubs. «Dirty» air in residential areas of industrial cities creates a high environmental risk and threat to public health. It remains relevant to study specific dependencies and factors for building a green framework in man-made areas of cities based on new opportunities provided by Digital-technologies.

Let us discuss the provisions in support of the presented research hypothesis.

Fundamental principle No 1 – the priority of the sanitary function. In man-made spaces, numerous stationary and mobile emission sources operate simultaneously and continuously, saturating the ground layer of the atmosphere with toxic impurities (dust, soot, aerosols, gases) and negative physical impacts (excess heat, noise, odors, vibration, electromagnetic and ionizing radiation). Therefore, the balance of ecological, aesthetic, functional, social and cultural requirements is practically unachievable and cannot be an end in itself. The greening object must provide risk-free sanitary and hygienic conditions for short-term presence of people in the workspace and a safe living environment in the adjacent areas (Refaat, 2014.). The biological capabilities of plants are limited, so many useful ecosystem services and functions of green spaces are not relevant (Fig. 1).

ASPECTS OF «SMART» GREENING OF TECHNOGENIC SPACE	
Actual	*Not Actual*
Ecosystem functions of green spaces	
– assimilation capacity – dust and aerosol capture – high gas resistance – biological productivity, biomass	– fire protection – oxygenation – aesthetics – mood and emotional restoration, recreation – architectural expressiveness (silhouette, structure of the

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accumulation, photosynthesis – assimilation capacity – dust and aerosol capture – high gas resistance – biological productivity, biomass accumulation, photosynthesis – adaptation to local conditions – climate and soil composition – favorable microclimate	trunk, branches, shape and color of leaves, flowers, fruits) – ecological niches for plants and animals
Innovative landscaping techniques	
- eco-parking - a digital twin of an object, the structure of which ensures the prompt collection, accumulation, processing of data, analysis and management	- вьющиеся растения, вертикальные живые изгороди, зеленые крыши и фасады зданий, деревья в ящиках - декоративные цветники и газоны - искусственные водоемы, фонтаны

Figure 1: Aspects of «smart» greening of technogenic space.

Fundamental principle No. 2 – ***zoning of the buffer territory***. When the emission moves from the source towards the residential development in the direction of the wind, the impurities are dispersed and their concentration changes (Krupina, 2016). Therefore, the intensity of pollution also changes in the buffer territory, which allows us to allocate areas for the most rational and harmonious landscaping (Fig. 2).

Section of active pollution zone	Pollution level of the receiving layer of the atmosphere and the tasks of "smart" landscaping	The construction of a smart greening facility
Strip of precipitation (smoke)	Evere gas contamination: maximum concentration of marker significantly exceeding sanitary standards. The task is to destroy concentrated forms of polluted air flows.	Width 500-700 m. Gas-resistant tree species and special care and watering regimes. The design ensures the formation of a system of aerodynamic corridors for active ventilation, intensive air exchange and dilution of emissions with fresh air.
Absorption band (variable gas content)	A slight excess of the safe concentration of marker substances. The task is active dispersion of impurities	Width 600-1000 m. There is an influx and accumulation of impurities from the first strip. Trees of average gas resistance. The design allows for maximum absorption and assimilation of marker impurities
Low Pollution Band (Full Scattering)	Weak and stable concentration of marker substances within the background value. The task is to filter and further clean the air to protect the population from wind, odors, noise and dust	Width 100-200 m. Weakly gas-resistant trees and shrubs. The design creates conditions for thermal and dynamic turbulence of air flows, effective dispersion of residual impurities in the environment

Figure 2: Main zones of the buffer territory.

Fundamental principle No. 3 – ***the relationship between «source + marker substance + active pollution zone» and the dispersion mechanism***. The ecological footprint of a man-made object is formed as a result of complex cause-and-effect relationships: «industry technology → emission source → pollutant (marker) → gas purification system → emission source → green buffer area → dispersion in the atmosphere → pollution zone → damage» (Krupina, 2016). In the airspace of large industrial cities, pollution clouds are layered on top of each other, penetrating residential areas and social facilities. The key task in designing greenery is to identify areas that may be subject to active negative influence – active pollution zones (APZ). For an industrial hub with high-altitude emission sources, it extends to an area up to 40 heights of the highest source. Complex calculation methods are used to determine the APZ from motor vehicles moving along highways. Thus, the introduction of high green spaces into the volumetric planning composition of main streets causes significant changes in the transformation of wind and the aeration regime of dispersion of impurities, their spread to the upper floors of buildings and the distribution of areas of increased concentration. In cities with dense frontal development, semi-closed volumes in the form of canyons are formed, where air pollution is focal in nature due to the appearance of a closed circulation of vehicle emissions, which prevents air exchange in transverse prevailing wind directions (Balakin, Aleksikov, Azarov, 2023).

The initial object of data collection, accounting and control is the source-substance system - local natural and climatic conditions. The reduction of air pollution on motorways and streets by green spaces occurs due to dispersion of transport emissions in the upper layer of the atmosphere when air flows around greenery objects. The scattering capacity of green belts is determined by the number of rows, height, crown shape and density of phytomass of trees and shrubs. On high-speed highways, it is recommended to use multi-row plantings of trees with dense, closely-closed crowns and undergrowth with shrubs of a stepped shape. In pedestrian areas and public spaces there are green strips of a ventilated structure with the height of the trees equal to half the height of the buildings. Herefore, in street canyons, it is necessary to limit the height of trees near the middle floors of buildings to ensure sufficient air exchange and reduce the concentration of emissions, and also to prevent the development of trees and shrubs over the roadway and sidewalks by carrying out constructive cutting, thinning, clearing and mowing.

Let us systematize the factors that determine the mechanism of dispersion and assimilation of pollutants coming from the source (Fig. 3). They can be divided into three groups – characteristics of the emission source, characteristics of pollutants, and local meteorologicaland climatic and other external conditions (Ivanova, Nader, Mishakov, Shapovalova, Ivanova, Azarov, 2020.).

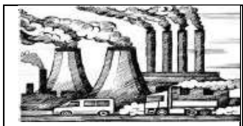	***FACTORS DETERMINING THE LEVEL OF POLLUTION OF THE ATMOSPHERE'S GROUND LAYER IN THE AREA OF A MAN-MADE EMISSION SOURCE***	
EMISSION SOURCE PARAMETERS	**PARAMETERS OF THE MARKER SUBSTANCE**	**EXTERNAL AND CLIMATIC CONDITIONS**
- height -mouth diameter - cross-sectional area - power - discharge temperature - discharge humidity - volumetric flow - linear velocity -- distance from the source at which the maximum concentration is recorded - chemical composition of the emission - mass of the maximum permissible emission ¬ distance from the source to residential areas	- name - sanitary hazard class - lifetime (decay) ¬ transformation mechanism - maximum permissible concentration - maximum concentration in emission - background concentration - maximum permissible emission standard - substance hazard category - physical properties of the emission	- vertical stability of the atmosphere - wind direction and speed, including dangerous - ambient temperature, its daily and seasonal fluctuations - terrain topography, relief, buildings - relative position of man-made objects - landscaping of the buffer zone - inversions - cloudiness - radiation - background impurities

Figure 3: Factors influencing the level of air pollution.

It has been revealed that in an urban environment the mechanism and result of dispersion of harmful transport emissions are determined by meteorological conditions: relative humidity and air temperature, wind speed and angle to the road, length of the section, intensity of cars and trucks, average speed of traffic flow, longitudinal slope of the roadway, degrees. For example, at a distance of 20 m from the roadway of a transport highway, a dangerous concentration of CO is practically not observed, and at low wind speeds, the most unfavorable conditions occur at a wind angle to the road of 30^0. The dispersion of impurities in the surface layer of the atmosphere refers to diffusion processes and is described by various mathematical models. A review of the advantages and disadvantages of models as applied to an urban environment characterized by a variety of buildings, intersections of transport routes, and overlapping emissions from numerous enterprises (with different heights and intensity of emission sources) is presented in (Kurakina, Myshko, 2020). External factors that determine the intensity of vehicle pollution include the height and proximity of residential and public buildings to sources, background air pollution, the presence of greenery, socio-economic characteristics, design features of the highway (road width and speed limit, type of surface, height above ground level, presence of a protective screen), traffic characteristics (type and number of vehicles, average speed, number of intersections with traffic lights), The calculated mass emissions under specific conditions of impurity dispersion are the algorithmic basis for modeling the concentration of pollutants from linear and other sources, and the result is a spatial pollution model.

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External factors that determine the intensity of vehicle pollution include the height and proximity to sources of residential and public buildings, background air pollution, the presence of greenery, and socio-economic characteristics. They are also influenced by the design features of the highway (road width and speed limit, type of surface, height above ground level, presence of a protective screen), traffic characteristics (type and number of vehicles, average speed, number of intersections with traffic lights).

The calculated mass emissions under specific conditions of impurity dispersion are the algorithmic basis for modeling the concentration of pollutants from linear and other sources, and the result is a spatial pollution model (Aleksikov, Balakin, Faizaliev, 2023).

Fundamental principle No. 4 – ***The scientific selection of biological plant species by marker substances.*** The most significant impurities, the share of which is more than 85 % in the mass of emissions from the source and not less than 10 % of the total emissions from the production facility, are markers. This category is used in the practice of regulating the risks of environmental pollution by emissions. The list of markers is established on the basis of a labor-intensive calculation of a set of indicators, which allows for an objective assessment of the negative impact of a specific emission source and the enterprise as a whole, optimization of economic costs for reducing the mass of emissions, and competent organization of environmental monitoring.

Biological species of plants with different activity decompose organic impurities with the help of their own enzymes into inorganic compounds, some of which accumulate in them, the other part passes into a volatile form and is released into the environment in a harmless form (Prokofieva,., Vasiliev, 2019). The process of absorption, assimilation and transformation of pollutants by plants is called phytoremediation (Fig. 4).

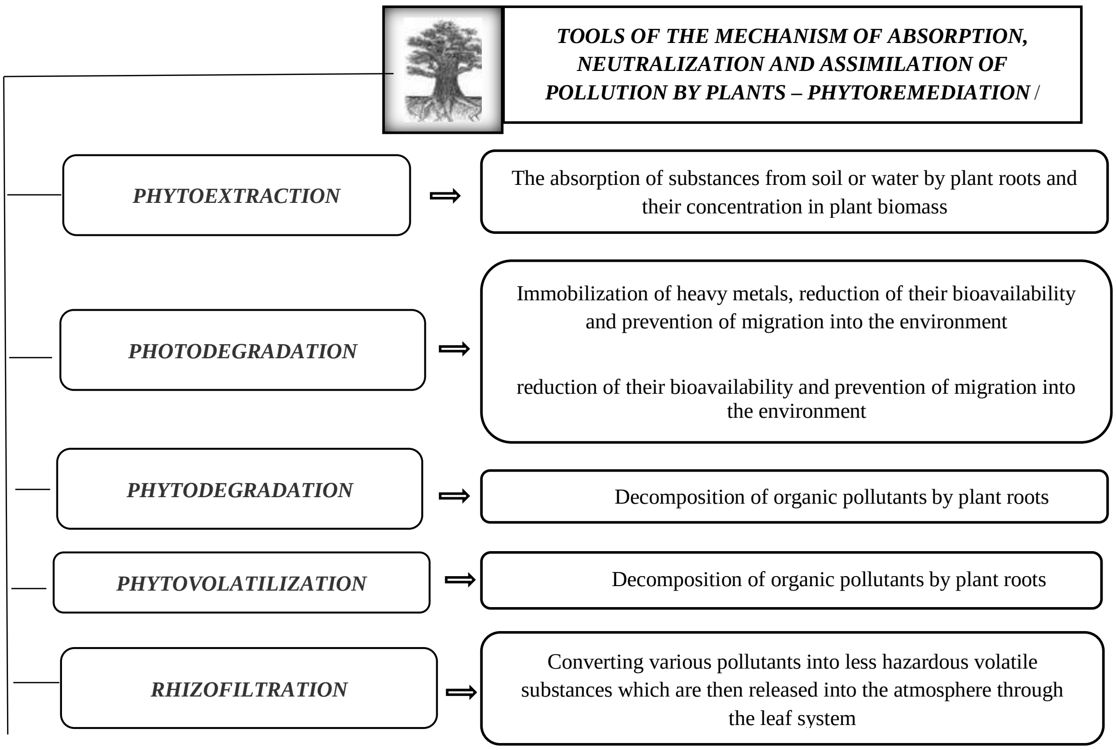

Figure 4: Instruments of the phytoremediation mechanism.

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Plants are characterized by different mechanisms of adaptation to factors of the technogenic environment and realize their adaptive potential in different ways, which allows them to successfully adapt to changes in growing conditions and perform ecosystem functions as effectively as possible as part of the city's green infrastructure (Sarbaeva, 2024). Biological properties, gas resistance, characteristics and mechanisms of functioning are the primary basis for choosing plants for landscaping man-made spaces with a high index of atmospheric pollution,

Fundamental principle No. 5 – ***The optimization of spatial planning and object design.*** The design of the environmental protection greening object determines the alternation of circulation zones through which polluted emissions are actively carried into the upper layers of the air and dispersed. The efficiency of pollutant assimilation depends on the width of these zones and the height of the trees. The level of greening of buffer territories should be high enough, at least 60-70% of the total area (Krupina, 2016).

Plantings of trees and shrubs have a dense (insulating plantings) or openwork (filtering) structure. The first creates a mechanical isolating barrier in the form of a strip and 3-5 rows of trees (distance between them 2 m) and 2-3 rows of shrubs (distance between them 1 m) on the path of the emission flow, which contributes to the sedimentation and absorption of a large amount of impurities. The second – with the help of a strip (50-100 m wide) of closed crowns of well-leafed plants creates ascending air currents and acts as a green mechanical-biological filter. Multi-row linear strips of plantings with dense, densely closed crowns, located along highways within 15-30 m, reduce the concentration of harmful substances in the air by 50% by increasing the dispersion height [4]. Their gas-protective efficiency depends on geometric and design characteristics that determine their aerodynamic qualities - the number of rows, height, density and closeness of the stand, the presence of shrubs in the lower tier. The height of trees in the plantings should not exceed half the height of the buildings.

Fundamental principle No. 6 – ***The optimal operating mode of the facility.*** «Smart» greening is a single intelligent space in which plants and sources of influence are monitored in real time. Modern sensors and detectors placed at observation posts or on unmanned aerial vehicles collect data on the condition of green spaces and the concentration of substances in the air. This allows achieving the following results:

- operational control of temperature, soil moisture, air, illumination, insolation, marker concentration;
- automated systems for regulating the consumption of water, fertilizers, lighting; optimization of the aeration and ventilation regime;
- minimization of costs, neutralization of the risk of the fatigue element of the "human factor" by reducing the labor intensity of plant care operations to maintain their high filtering capacity;
- automation of the plant irrigation and fertilization system, saving water and reagents due to point dosing taking into account weather conditions and plant needs (there is no overspending or loss);
- optimal combination of moisture and nutrients taking into account the local climate and soil composition; - rational use of fertilizers with minimal damage to the local soil type, groundwater and natural ecosystems.

Fundamental principle No. 7 – ***The neural network technologies.*** «Smart» landscaping, as a combination of scientifically based spatial planning of special areas of stable perennial plants and neural network technologies for their exploitation, helps to overcome social and environmental problems of man-made territories (Smart Parks, 2022):

- degradation of the mechanical and biological state of the landscape;
- critical level of pollution of the urban environment;
- reduction of the economic potential for development of the territory;
- lack of effective principles regulating the situation with anthropogenic territories in the urban environment, taking into account the utilitarian needs of the population and the strategy of territorial development;

– optimization of the environmental protection budget.

«Smart» landscaping is based on a data array, and digital technologies provide the right comprehensive solutions to the following problems:

– selection of vegetation types, sizes, shapes, comparison of spatial planting layout options;

– forecasting the useful life of landscaping objects through assessment of the filtering, adsorption, assimilating and neutralizing capacity of plants in relation to marker toxicants;

– determination of the operating mode and conditions for productive growth and development of greenery objects taking into account the life cycle phase;

– inventory, condition monitoring, maintenance, spot watering, pruning, protection from diseases and pests, compensatory felling;

– calculation of maximum permissible functional (recreational) loads for various types of disturbed areas;

– ensuring prompt awareness of the local community on issues of the ecological state of the territory and environmental activities of enterprises, involvement of the population in the discussion of publicly significant life-supporting decisions;

– search for areas of diversification, progressive environmental improvement and new ways of sustainable development of territories in a state of continuous anthropogenic use.

4 CONCLUSION

Thus, «Smart» greening of man-made territories is the integration of environmental and digital technologies to achieve vital values – a natural and safe man-made environment, compliance of the air of industrial cities with sanitary standards, ensuring social responsibility, sustainability and efficiency of economic activity.

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